Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	
Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies	)	ET Docket No. 03-108
	)	
Authorization and Use of Software Defined Radios	)	ET Docket No. 00-47 (Terminated)
	)	

COMMENTS BY HYPRES, INC.

MAY 3, 2004

HYPRES, Inc. is submitting these comments in response to the solicitation for information in the NPRM adopted December 17, 2003.

HYPRES, Inc. is a manufacturer of exceptionally high-performance and cost-effective electronic equipment using Superconductor Micro Electronic (SME) technology. HYPRES has demonstrated digital circuit capabilities that far exceed the performance currently available and forecasted with semiconductors and other implementations. The performance of SME circuits enables real-time processing of RF signals in the digital domain with unprecedented accuracy and speed at frequencies previously unattainable. HYPRES technology brings the power of digital processing to the RF domain. The technology is so accurate it defines the volt; so sensitive it can measure brain currents, and so fast that it can directly convert RF signals.

In these comments HYPRES responds to some of the questions asked in the NPRM, and indicates areas where the performance SME technology can make a substantial contribution to effective implementation of Commission Policy Cognitive Radio (CR) technology. We encourage the Commission to take steps to support emerging technologies that can facilitate introduction of these concepts. We also comment on use of the term "Cognitive Radio" and point out some problems associated with its use.

Cognitive Radio

Emerging technologies make possible new system-level approaches that show promise for improving spectrum management, establishing a real-time economic market for underutilized spectrum, increase efficiency of operation, and permit coordination between spectrum users wishing to operate concurrently. HYPRES supports these goals, and, as we shall describe below, offers technology in the market that will greatly facilitate their attainment.

The generic term "Cognitive Radio" (CR), however, has been introduced to describe a wide range of capabilities collectively. Mitola[1], who coined the term, describes a CR Cognition Cycle composed of a number of distinct activities. He describes them as Observe, Orient, Plan, Decide, and Act, and provides a diagram depicting their interaction. He also describes a set of levels of cognitive activity.[2] Mitola also notes some imprecise use of the term CR.[3]

The NPRM document uses the term "Cognitive Radio" in describing attainment of a variety goals when, in fact, it is one or two of the constituent technologies that are

[1] Mitola, Joseph, III, Cognitive Radio, An Integrated Agent Architecture for Software Defined Radio, Doctoral Dissertation, 8 May 2000, Pg. 47
[2] ibid, pg 49
[3] ibid, Pg. 206

responsible. For example, at ¶10, the NPRM[4] says "A cognitive radio (CR) is a radio that can change its transmitter parameters based on interaction with the environment in which is[sic] operates." So two functions are identified in the definition: changing transmitter parameters, and interacting with the environment. These activities are at the lowest two levels of Mitola's Radio Cognition Tasks.

We suggest that it is appropriate to be more precise on the use of the term "Cognitive Radio". Some of the levels are more controversial than others, and many of the Commission's objectives can be attained without invoking undue concern associated with the higher levels. For example, a PCS operator who has paid a great deal of money for a spectrum license may object to access by unlicensed radios, where the noise floor may be raised to the detriment of the level of service provided to paying customers. That operator, in presenting to a Legislator an objection to intrusion by "Cognitive Radio", is using a broad brush that could unnecessarily tar all of the CR technologies. It would be unfortunate to confuse the subject of debate in a legislative venue due to lack of clear terminology in the CR space.

HYPRES supports use of the term "Cognitive Radio", but suggests that the language of proceedings reserve the term to refer to the collective set of technologies. We propose the following segmentation, based on the Mitola elements described above, of the CR space as an example of improved functional clarity.

[4] Federal Communications Commission, Notice of Proposed Rule Making and Order, Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Techniques, ET Docket No. 03-108

Observe. Acquisition by the radio of traffic, control, beacon, pilot channel, geolocation, and sensor information that constitutes not only RF input to implement the basic communications operations of the radio but provide additional information to support decision-making.

Orient. Action within the radio to correlate incoming information to the proper source and allocate it appropriately to the internal radio knowledge structure.

Plan. Policy-based consideration of state or status changes in received information and internal functions, consideration of alternate courses of action

Decide. Selection of actions from the proposed plans.

Act. Implementation of proposed actions, such as notifying the user of changed conditions or changing transmitter parameters such as modulation type, frequency or power level. Activation of the transmitter and RF emission if required.

HYPRES suggests that the Commission adopt a reference model of the CR space, such as that described above, to make clear the structure of the constituent technologies, and indicate which of them are under consideration at in a given discussion. If these specific terms are not deemed appropriate, any set that accomplished the objective of clarifying the issues would satisfy the concern.

Cognitive Radio Technologies

HYPRES, Inc. SME technology provides RF performance to support and enhance the Observe and Act categories mentioned above. It also makes a contribution to the Orient and Decide functions. As described below, HYPRES has relevant capabilities in correlation-based reception and transmitter pre-distortion. Detailed description of these capabilities is provided in the Attachments.

HYPRES is confident that its technology, as part of the emerging hardware and software performance improvements, will support Commission goals of spectrum policy revision, and introduction of Cognitive Radio concepts to the problems of spectrum availability and enhanced utilization. We urge the Commission to take the increased performance available with SME into account when considering proposed rules.

As with any new technology, there are technology transfer impediments associated with widespread adoption. Network operations will be enhanced, and the Commissions objectives advanced, by widespread improvement in radio performance as offered by new technologies. We thus recommend exploration of incentives for adopting new technologies such as HTPRES SME and operating with enhanced infrastructure performance.

Radio Implementation

In this section we provide an overview of the HYPRES capability, and provide some references to the NPRM. Figure 1. shows a high-level reference model of the HYPRES Radio and its constituent modules. Further details are presented in the Attachments.

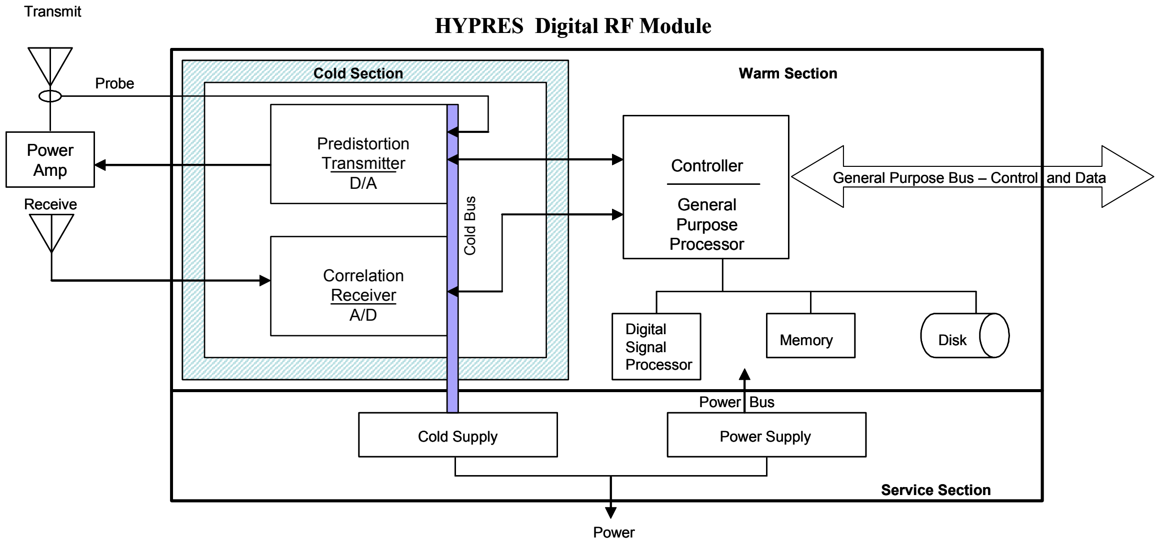


Figure 1. The HYPRES Digital RF Module

In the receive path the autocorrelation techniques we have discussed permits extraction of any desired channels from the received signal, and to respond to changes in real time. This capability is limited only by the inherent response characteristics of the antenna aperture. This capability is in direct support of the monitoring capabilities described in the NPRM at ¶24, 25, 30, and 46. It is also ideal for the beacon approach described at ¶57-61 and 63, an approach to control over spectrum leasing with reasonable response time and fail-safe provisions.

Following extraction of the desired signals, they are auto correlated, demodulated, and delivered for further processing. This is where the Orient function is completed, and the information prepared for rule-based Adaptive processing.

The transmitter path in Figure 7 shows the HYPRES approach to transmitter management using predistortion. The digital signals to be transmitted come into the transmitter module where they are digitally combined, and sent to the antenna through a power amplifier (PA). A probe on the PA output brings a sample of the transmitted signal back to the transmitter module, where it is compared with the desired signal. Any differences are extracted, inverted, and added back into the primary feed, thus correcting for distortion introduced by the PA, and permitting it to operate on non-linear portions of its characteristic curve.

The result is total spectrum management. It includes sensing using HYPRES unique spectrometer capabilities, followed by high spectral density communications capability, using intelligent controllers. In effect, we "sniff" the spectrum with great precision, find available spectrum (in one piece or in parts), transmit in the available spectrum with high spectral density, and change it (on the fly) in real time. This capability clearly supports the Commission vision of Observing the environment and Acting upon it.

Radio Security

Security in systems using CR technology gives rise to a number of considerations, as mentioned in NPRM at ¶22, 30, 51, 83, 92, and 98. Figure 2 shows a version of the HYPRES Digital RF radio front end with the addition of a Radio Security Module.

The cryogenic chamber required for superconductor operation must cool a volume the size of an LSI chip. That volume is very small, is very small, of the order of .05 cc. This very compact space assembled inside of the requisite thermal insulation is physically very secure. Because all of the radio transmission and reception is passing through that module, we can exercise a great deal of control over the throughput signals. By introduction of a Trusted Agent, we have the potential to perform a number of operations, including monitoring beacon signals, and interrupting the transmission signal if it violates the policy rules or if the beacon signal requires it. As the trusted agent has a cryptographically secure link to a central authority, software compromise of its functions are deterred. The module is safe from both physical and software-based tampering, and provides independent control over the behavior of software downloaded into the radio..

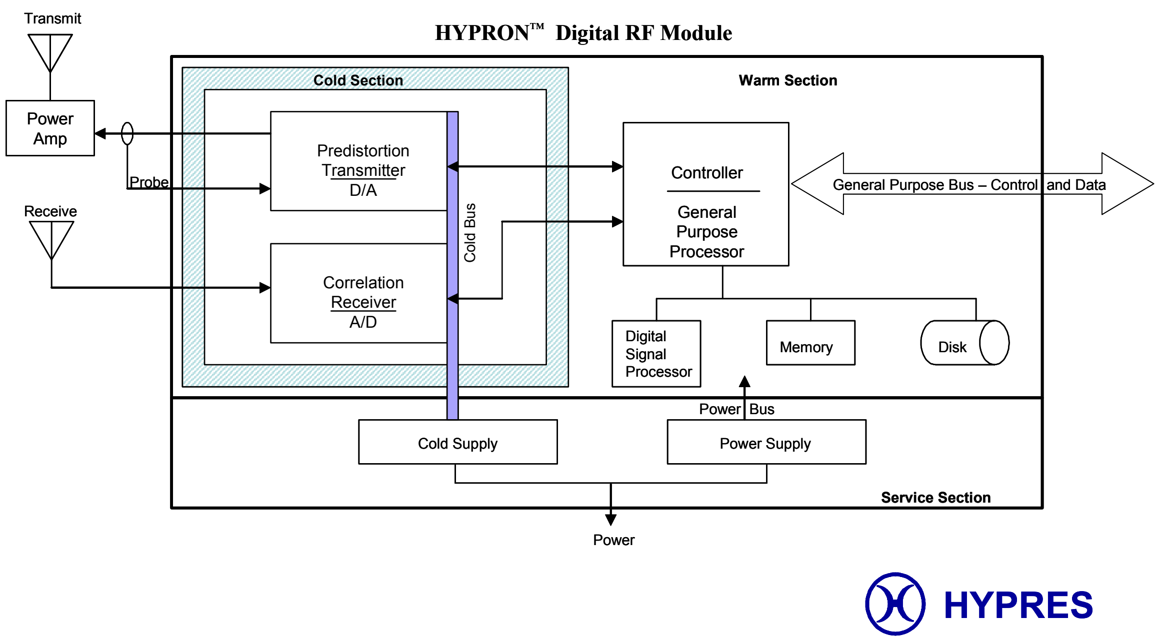


Figure 2. HYPRES RF Security Module

So another enabler for CR functionality with a high degree of assurance is possible with the security provisions of the HYPRES Digital RF radio front end.

Conclusion

HYPRES is confident that its technology, as part of emerging hardware and software performance improvements, will support Commission goals of spectrum policy revision and introduction of Cognitive Radio technology to permit greatly increased utilization of spectrum. We urge the Commission to take the increased performance available with SME into account when considering proposed rules. We also recommend exploration of incentives to operating with enhanced infrastructure performance.

We appreciate the opportunity to comment on the Cognitive Radio NPRM and ORDER.

Respectfully submitted,

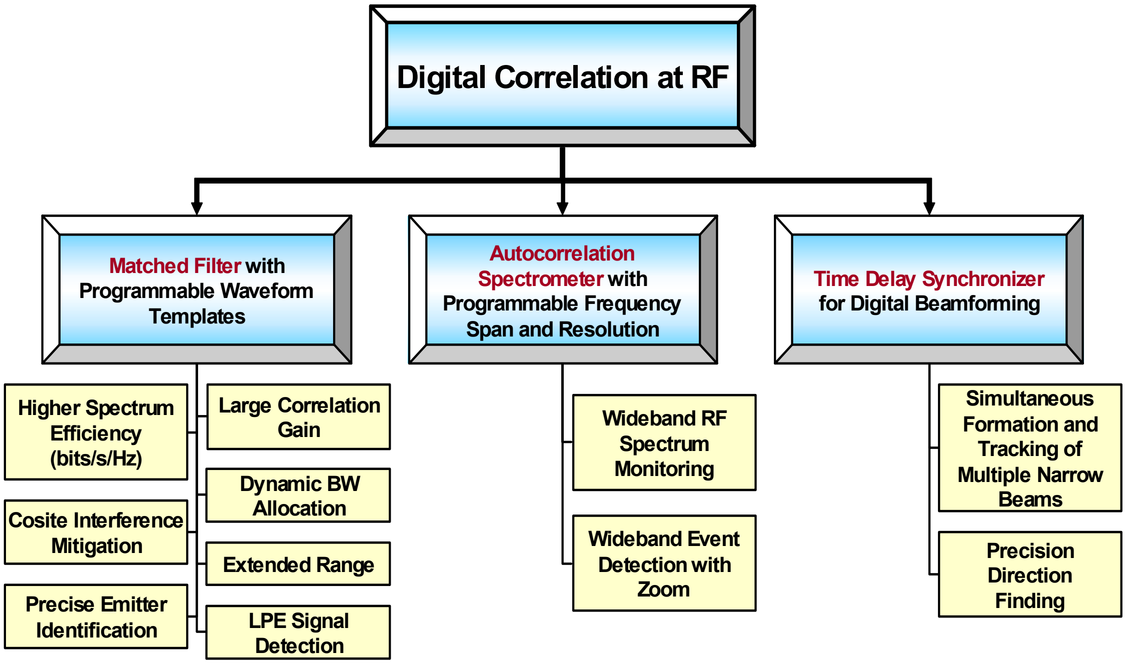
Peter G. Cook
Senior Member of Technical Staff
HYPRES, Inc.

May 3, 2004

ATTACHMENT A

High Performance Radio Technology

This Attachment provides details on how the HYPRES superconducting technology provides radio performance to implement the Observe and ACT functions described above. We describe the utilization of SME correlation capabilities to achieve three distinct classes of digital signal processing for enhanced radio performance, spectrum management, and other objectives of future radio development. The classes are (1) cross-correlation matched filter, (2) autocorrelation spectrometer, and (3) time-delay synchronizer. Major features of these are shown in the figure below. The matched filter improves communication capacity and precision of emitter identification. The spectrometer permits dynamic spectrum management and the synchronizer allows tracking, direction finding, and nulling. Furthermore, the lower noise of the cryogenic superconductor receiver permits higher data rates, as well as detection of weaker transmit signals. By bringing the flexibility, fidelity and scalability of digital processing to the traditionally analog RF domain, this technology contributes to the objective of replacing custom analog systems with modular, general-purpose digital systems. While the above focuses on the receive side, similar capabilities can also be provided on the transmit side, to realize the full potential of the broadband, agile communication system.



The HYPRES Spectrum Management Receiver strategy is (1) an Autocorrelation Spectrometer with programmable frequency span to monitor a wide RF band and zoom in on any narrower part of this spectrum with proportionately higher frequency resolution, followed by (2) Cross-correlation Matched Filters for reception of signals-of-interest by cross-correlation with RF waveform templates from a library, aided by the spectral information derived by the autocorrelation spectrometer. This provides Near Real Time performance unattainable with conventional technologies, capitalizing on the unique features of HYPRES Superconductor Microelectronics Technology. Figures 1 and 2 show some details of the approach

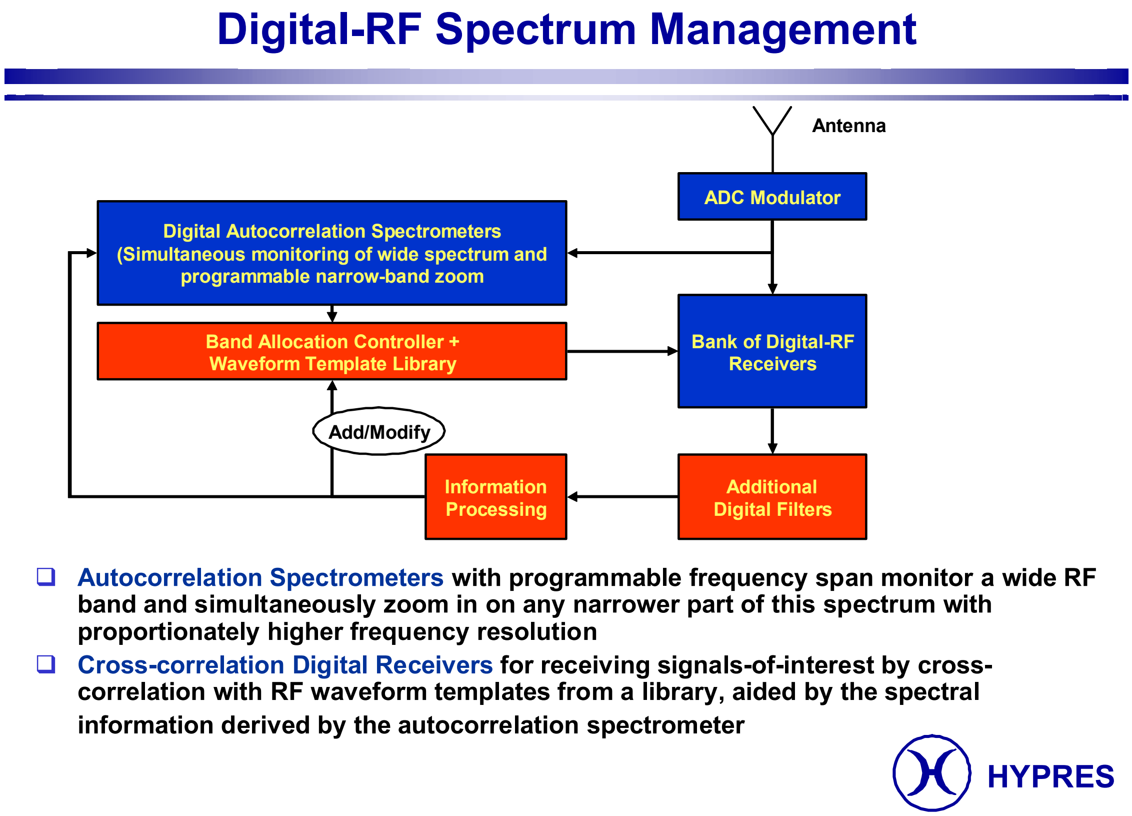


Figure 1. Digital-RF Spectrum Management

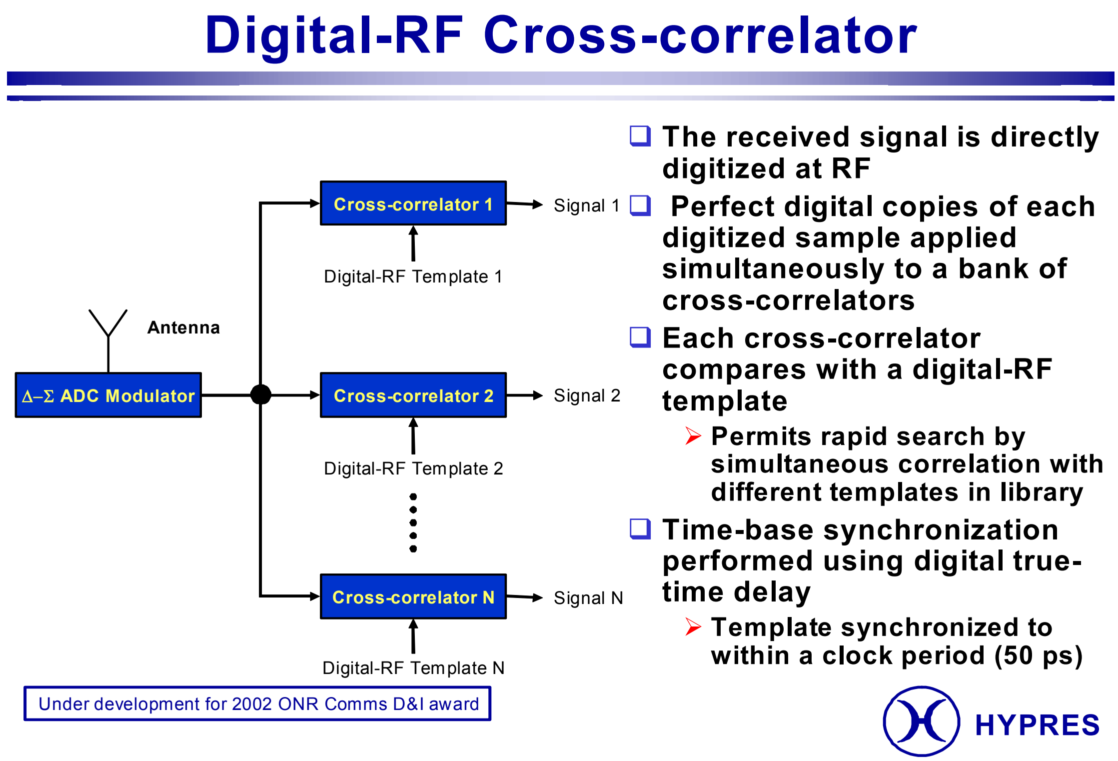


Figure 2. Digital-RF Cross-Correlator

The HYPRES broadband digital spectrometer will permit coarse spectral monitoring of the entire RF band, or fine monitoring (zooming in to MHz resolution or better) of any particular sub-band. This spectral monitoring provides an opportunity to detect changes in the local spectral environment, and can serve as an enforcement tool. Furthermore, together with high-level decision and control software, this spectrometer will enable true real-time spectrum management, with dynamic band reallocation and optimal spectral utility. Current capabilities are generally limited to static band allocation in order to avoid potential spectral conflict and reduce possible RF interference.

The novel features of this digital spectrometer are enabled by broadband, high-fidelity digitization and ultrafast (20-40 Gbps) digital processing of RF waveforms, using superconductor rapid single flux quantum (RSFQ) technology. Two central elements of such a digital-RF receiver, the analog to digital converter (ADC) and the digital correlator, have already been demonstrated by HYPRES in the laboratory. The low noise, high linearity, and high dynamic range of the superconductor ADC permits high-fidelity digitization of the entire RF band of interest, with detection of extremely weak signals as well as strong interferers. As we show below, by correlating the input signal with itself (together with a programmable time delay), we can extract the RF spectrum quickly and efficiently. By bringing the flexibility, fidelity and scalability of digital processing to the traditionally analog RF domain, this technology contributes to the objective of replacing custom analog systems with modular, general-purpose digital systems.

The block diagram of an autocorrelation spectrometer, with programmable span/resolution, is shown in Figure 3. The frequency span ($B = 1/\tau$) and resolution ($\Delta f = 1/M\tau$) can be programmed by choosing the autocorrelator time lag. The band of interest ($f_c \pm B/2$), which may be the entire receive band or any subband, is first digitally mixed down into separate upper and lower sidebands before performing the autocorrelation.

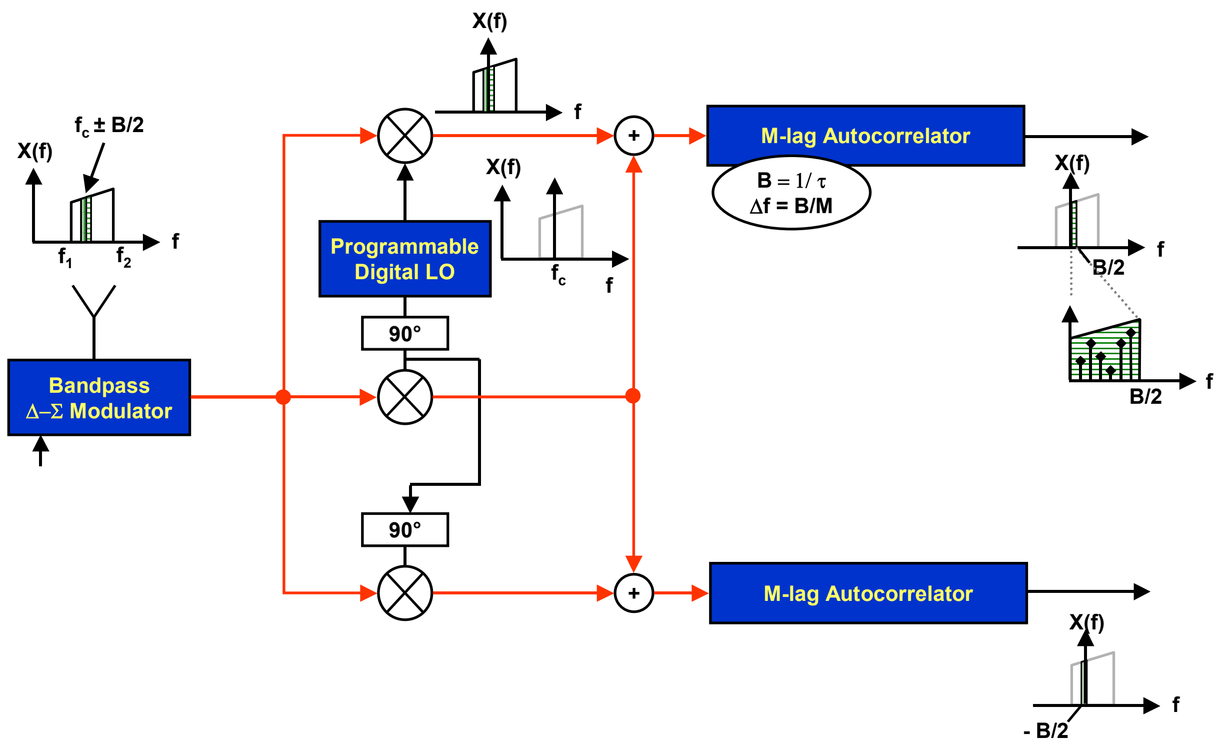


Figure 3. Autocorrelation spectrometer

As shown in Figure 1, the autocorrelation spectrometer can choose a band of interest (of bandwidth B, centered around f_c) within the receive band and resolve its spectrum with a resolution of B/M. The bandwidth and the center frequency are programmable. This allows one to monitor a wide band and then selectively examine narrower sub-bands with proportionately higher resolution.

The digital flexibility of this spectrometer permits the user to zoom in to any particular region of the RF spectrum, and examine the spectrum in this region with greater precision. This involves tuning the digital local oscillator (LO) to any desired RF frequency, under full digital control. No special-purpose analog LO or analog mixer is needed as part of the hardware.

The time-delay synchronizer enables the simultaneous formation and tracking of multiple beams in a "smart" antenna system. By controlling the precise time delay to a signal fed to multiple radiating elements accurate control of beam direction can be realized. With the antenna location and an azimuth to a target a line of position (LOP) can be formed. Multiple LOPs enable precise geolocation. Nulls can also be steered to avoid reception of energy from sources of interference.

In a previous section we have proposed dealing with the CR space in terms of the subdivisions Observe, Orient, Plan, Decide, and Act. With that partitioning in mind, we indicate that the HYPRES SME technology is a primary enabler in the areas of Observe and Act, with in important role also in Orient. The unparalled high performance and inherent low noise of the HYRPES Digital RF front end make possible delivery of information in real time as a basis for a number of system capabilities in the remaining components.

Another facility available under the HYPRES technology is transmission pre-distortion. The very high performance of the SME circuits introduction of an inverse signal into the digital processing that precedes digital to analog conversion.

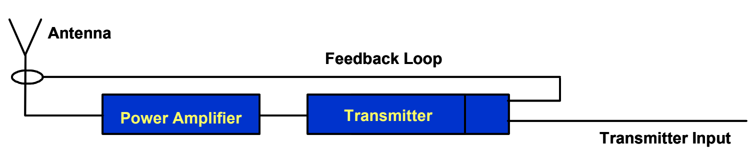


Figure 4. Transmission Pre-Distortion

As shown in Figure 4, the transmitted signal is sensed at the output of the power amplifier. This signal is compared with the incoming signal in real time to generate an error signal that can be inverted, and applied to the input to the transmitter. The power amplifier exciter input is thus distorted so as to linearize its output. Crucial to the success of this function is the very high performance of the SME circuits to enable realtime comparison. This capability ensures a very high degree of spectral purity in the transmitted signal.

ATTACHMENT B

Superconducting Micro Electronic Capabilitiess

The following are features of the HYPRES Superconducting Micro Electronic capability:

Ultra-high digital logic speed. Single Flux Quantum (SFQ) devices are 10x faster than semiconductor, LSI implemented in SME is 50x faster than semiconductor.

Ultra-low power dissipation. Power required is 10,000x less than semiconductor technology. LSIC dissipates approximately 1 mW, swiching energy of 10^{-18} Joules.

Quantum accuracy. Individual flux quanta ($\square_0$=h/2e) are identical from the inherent quantum physics of superconducting circuits – 5 ppb accuracy at 10 v, basis of voltage standard.

Fundamental linearity. Very high Spur-Free Dynamic Range ADC and DAC.

Extremely high sensitivity. SQUID (ADC front ends) is the most sensitive energy detector. 60 dB better than conventional semiconductor front end. For example, -155dBm for 1 MHz BW with slope of 20 dBm/decade.

Extremely low noise. Receiver system noise $T_s \sim T_a$. Thermal noise at 4° K is 75x lower than room temperature.

Ideal interconnects. Zero path resistance means speed of light transmission, no RC delay. Low-impedance superconductor interconnects have negligible loss, dispersion, and crosstalk.

Simple, inexpensive IC fabrication. Thin film, about 10 steps, no expensive operations makes SME much less expensive that semiconductors for fabrication facilities and equipment to produce chips.

ATTACHMENT C

Superconducting Micro Electronic Benefits

The following are benefits for spectrum management provided by the HYPRES SME technology:

- Ultra fast correlation resulting in more rapid acquisition and superior processing.
- Rapid identification through digital-RF cross-correlation with library waveforms.
- Reduction of minimum detectable by over 10 dB with low-noise ultra-sensitive front ends.
- Large near real-time (over 30 dB) correlation processing gain in signal-to-noise ratio for rapid ID, over 90 dB processing gain in 1 second.
- Enhanced range of acquisition and signal processing.
- Mitigation of co-site interference
- Significantly improved direction-finding for geo-;ocation
- Higher resolution aand dynamic range
- Ultra wideband capability
- Robust all-digital design provides “six-sigma” availability